DYNAMIC CHARACTERISTICS OF END RELEASE SEATBELT BUCKLES

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ABSTRACT

Can a buckle designed with a lock for the latch when struck on the face, back, or side, also have this same feature when accelerated along the longitudinal axis? Six seatbelt buckles from various manufacturers were tested to determine their dynamic characteristics in the longitudinal direction along the mounting stalk. Patented designs of the buckles were intended to prevent inertial unlatching of the buckle. Although they may perform well in lateral and vertical directions, when force is applied along the direction parallel to the mounting stalk the buckles could be made to release. If the buckle is mounted in the vehicle with a rigid stalk, could impact pulses be transmitted to the buckle to cause release?

A test apparatus was constructed where the buckle could be mounted with the stalk and webbing. The webbing could be preloaded and the buckle was accelerated by impacting the mounting point at the base of the stalk. This acceleration pulse was studied for the effect of the preload on the webbing and to determine the minimum pulse required to release the buckle.

This study documented the acceleration required to cause a buckle and latch plate to inertially release. The acceleration required causing the unlatching of the buckle increased as the preload of the webbing increased up to 100 pounds. Any preload in excess of 100 pounds prevented inertial unlatching.

It was also found that the threshold of inertial unlatching is not so much a function of the maximum acceleration, as it is the area under the acceleration curve which is the change in velocity.

INTRODUCTION

Inertial unlatching is where the seatbelt buckle can be opened with an impact to the buckle. The subject has been studied and discussed since the 1960’s. Blick, Harcourt, Syson, and Hille presented a paper at the Association for the Advancement of Automotive Medicine in 1996 wherein they discussed “Theoretical and Experimental Analysis of Inertial Release of Seat Belt Buckles.” They showed that the buckle release was related to the impact of the hip to the buckle. In the same year Andreatta, Wiechel, MacLaughlin, and Guenther developed a mathematical model, which predicted the dynamics of an RCF-67 buckle when struck on the back. (SAE 960436) Thomas, Limbert, Lange, and Moffat showed that the acceleration required to release a buckle increased as the belt tension increased. They went on to show in their opinion that such combinations of acceleration and belt tension cannot occur during rollover collisions. (SAE Toptec 1993) James, Allsop, Perl and Struble do not state that such a release cannot happen, but the opinion is expressed that during collisions the circumstances do not exist to cause a release. (SAE 930641) The fact is acknowledged that a collision is a chaotic event and consists of many possibilities. Expressing an opinion that would represent all of the possibilities which can occur in a collision cannot be done with only a few experiments.

Testing methods used to evaluate the buckles include striking the buckle with a pendulum or a striking device where the speed of the striking device can be controlled and the striking surface hardness can be changed; monitoring a vehicle rollover with dummies placed in the restraint system; or striking the buckle on the back with a mallet, across the knee, or even with the palm of the hand. The basic criteria for a failure in the test is simply if the buckle opens during the impact. The first type of tests was conducted by Moffat, Thomas, Lange, and Limbert at a laboratory at Failure Analysis. Their results were presented at an SAE Toptec in 1993. Sances also used the technique of striking the buckles with a pendulum and recording the accelerations. (“Spinal Injury Due to Inertial Unlatching of Vehicular Buckles,” “Biomechanical Analysis of Restraint Receptacles – ASME 1998.)

The second test method, that of rolling the vehicle, was also used by Moffat, et al. In the few tests that were performed, the buckle did not release. However, there have been inertial releases recorded during sled and crash tests performed by NHTSA. These are:

1. 1980 Subaru GLF, 35 MPH frontal NCAP 79-19-No1-094: NHTSA 800547: F-2580,
2. 1980 Datsun 310GX, 35 MPH frontal –NCAP 79-17-No1-096; NHTSA 800546; F-2532,
3. 1984 Plymouth Conquest, 35 MPH frontal – NCAP 79-17-No1-284; NHTSA CE0302,
4. 1989 Suzuki Sidekick, 35 MPH frontal – NCAP 79-17-No1-516; NHTSA Mk0502,

The third test method has been used at General Motors to determine if a seatbelt buckle is defective. Mr. Donald Brown, the service director at a dealership in Overland Park, Kansas, was trained by General Motors to strike the back of the buckle to determine if it was defective. If the buckle opened during the strike, it fails the test and is defective. This method was brought out in a deposition on July 30, 1999 in the case of Jones v. GM. Although this test had been deemed a "Parlor Trick" by officers of GM, the court allowed the testimony of a police officer that testified this was the method he used to test the belt buckle.

Acknowledging the problem of inertial unlatching of seatbelts, as many as 72 newly designed production seatbelt buckles have been manufactured and installed in automobiles, and more than 150 lock-for-the-latch patents have been issued to various manufacturers and inventors.

But in a case where buckles are mounted in a vehicle with a rigid stalk, impact pulses can actually be transmitted to the buckle and cause release. Furthermore, Richard Clarke of Clarke Automotive Consultants has shown that the acceleration on the floor pan of a vehicle during a rollover can be amplified 4 to 5 times before it reaches the buckle.

This study shows that the inertial release of a seatbelt buckle is directly related to acceleration over a given time period. The study also shows that a rigid stalk such as a stiff cable or steel mount will allow an acceleration to be transmitted from the vehicle structure to the buckle causing an inertial release. The study was conducted in order to measure the acceleration required to cause an inertial release of six different models of buckles. The models are as follows:

1. Model NSB1055 NSK-WARNER K.K
2. Buckle Pat No. 165857739B
3. Buckle Pat No. 4876772
4. Autoliv Model
5. Breed GBL1 Blocking Buckle
6. Buckle Pat No. 4645038

PROCEDURE:

Test Apparatus

The test apparatus consisted of four main components. The pneumatic cylinder, used to generate a given acceleration or velocity; a sled, which is used to transfer the energy produced with the pneumatic cylinder to the test cage; a rubber bumper mounted to the sled used as the contact surface; and a test cage in which the seatbelt buckle is mounted. The test apparatus is shown in Figure 1.

The test sled is attached to the pneumatic cylinder, which is driven by a reservoir of air. The pressure was regulated in the reservoir which provides a virtually constant pressure source of air to the pneumatic cylinder. By controlling the air pressure in the air reservoir, different velocities of the sled were produced. The sled travels on linear bearings and is stopped by a shock absorber at the end of its stroke. The sled impacts the test cage before it engages the shock absorber. The rubber bumpers are

Figure 1. Illustration of test apparatus.

screwed to the sled and are used as the impact surface. This attachment allowed for a range of durometers to be used as the impact surface which produced different acceleration pulses.

The test cage is a rectangular aluminum structure used to hold the buckle and latch plate during the test (see Figure 2). A load cell is placed between the latch plate and the cage in order to provide a means of measuring an adjustable pre-load applied to the connection. A short piece of webbing is used to attach the latch plate to the load cell. Four cables attached to the corners of the cage suspend the system from the ceiling allowing it to swing freely after the impact has occurred.

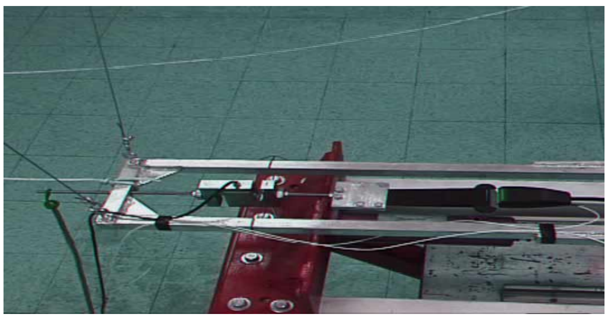

Figure 2. Test cage and buckle mount.

Data Acquisition

Two different data acquisition systems were used. Although the first system is a credible means of collecting data, it was determined that the particular data acquisition board in use at the time of the tests produced unreliable data. The following is a summary of the equipment used.

Equipment Used for System 1

1. Sled Accelerometer; PCB Model 308B; S/N 32532
2. Sled Accelerometer Power Supply; PCB Model 480E09; S/N 17838
3. Cage Accelerometer; PCB Model 353B16; S/N 9082
4. Cage Accelerometer Power Supply; PCB Model 480C02; S/N 2323
5. Buckle Accelerometer; PCB Model 353B16; S/N 58943
6. Buckle Accelerometer Power Supply; PCB Model 480C02; S/N 5727
7. Data acquisition board; National Instruments AT-MIO-16-L-9; S/N 013608
8. Add on board; National Instruments BNC 2080; S/N 000395
9. 60, 70, 80, 90-durometer rubber impact bumpers.

Using system 1, the data from the accelerometers was collected at a rate of 10,000 points per second.

Equipment Used for System 2

1. SOMAT eDaq data acquisition unit
2. TCE eDaq data acquisition software for eDaq test set-up
3. TCE Ease data acquisition software for data analysis
4. PCP 500 g accelerometer
5. PCP Signal Conditioner
6. Rice Lake Weighing Systems 10000 lb load cell
7. Fairbanks digital scale for reading load cell
8. 70, 80, and 90 durometers

Test Procedure

The test buckle was mounted into the aluminum cage. The latch plate was then inserted into the buckle. The belt tension was set using the load cell and scale. The durometer to be used was installed onto the ram. The regulator was then set to pressurize the air reservoir to the desired pressure. The air cylinder was next pressurized. Following this, the data acquisition system was initialized. The eDaq data acquisition software allowed data to be taken at 2500 Hz or 10000 Hz. It, also allowed a “trigger” to be programmed which allowed the unit to store data 10 milliseconds before a +/- 20g impact and for 500 milliseconds after impact. Finally, the sled brake was released, and the sled impacted the cage. After the data was collected in the SOMAT unit, the data was uploaded to Ease. The data was also uploaded to Excel for analysis.

RESULTS

All of the six buckles tested were subjected to similar conditions. These conditions produced inertial releases in 4 of the buckles. Two of the buckles tested didn't release in any of the tests. It should be noted that the maximum acceleration achieved with the current test apparatus was approximately 400 g's.

Table 1 shows release and non-release characteristics for 3 of the buckles tested at a pre-load tension of 5 lbs or less. Although the accelerations for these tests are not available, the table does show that inertial release can occur. As cylinder pressure increases, inertial release becomes more likely. As cylinder pressure increases, one would believe that acceleration also increases for the same durometer. By changing durometers, the time over which the acceleration occurs can be altered. At higher durometer values, less cylinder pressure is required to produce inertial release. It can also be determined that the required acceleration and time duration to cause a release is unique for each buckle.

Table 2 shows ranges of acceleration and the associated durometer and cylinder pressure combinations for 3 of the buckles tested. Note that pre-loads of 5 lbs or less are used. The reported accelerations are peak values of unfiltered data. The table also shows the ranges for which inertial releases occurred.

It can be seen that inertial releases occur throughout a wide range of accelerations. No releases occurred below an acceleration of 135 g. It can be seen that for the same buckle and similar accelerations, instances occur in which both release and non-release occur. It becomes rather obvious that acceleration alone may be a poor indicator of when a buckle will release.

A change in velocity can be determined by graphing the acceleration versus time and integrating the resulting curve. Figure 3 is a graphical representation of how the change in velocity may be determined. By comparing the change in velocities of tests conducted for an individual buckle, a trend develops relating the inertial release of the buckle to the change in velocity.

Tables 3 and 4 illustrates the relationship of the change in velocity to inertial release for two of the buckles. It also demonstrates why peak acceleration cannot be used as the sole criteria for determining when release or non-release occurs. As evident from the table, a minimum change in velocity can be determined in which release occurs. For values less than the minimum, release will not occur. A maximum value can also be determined for which non-release will occur. For values greater than the maximum, release always occurs. These values are specific or unique for each buckle. It should also be noted that for values between the minimum and maximum, both non-release and release occurs.

Table 1.
Durometer and Cylinder Pressure combinations producing release and non-release

Buckles	Durometer	Pre-Load (lbs)	Cylinder Pressure (psi)	Release
Buckle 2	90	2	15	no
		2	17	no
		2	18	yes
		2	19	yes
		2	20	yes
	80	2	20	no
		2	21	no
		2	22	yes
		2	25	yes
		2	30	yes
	70	2	30	no
	60	2	30	no
Buckle 3	90	2	18	no
		2	19	yes
		2	20	yes
	80	2	20	no
		2	22	no
		2	23	no
		2	24	yes
		2	25	yes
	70	2	24	no
		2	25	no
		2	26	yes
		2	30	yes
	60	2	30	no
NSB1055	90	3	13	no
		2	14	yes
		2	14	no
		3	15	yes
		5	15	yes
	80	3	15	no
		3	20	yes
	70	3	15	no
		3	20	no
		2	25	no
	60	4	30	no

Table 2.
Acceleration Ranges for Release and Non-Release

Buckles	Durometer	Pre-Load (lbs)	Cylinder Pressure (psi)	Acceleration Range (g's)	Release (Yes/No)
BUCKLE 3	70	1	25	294 - 318	0/3
		1	26	330 - 355	0/2
		1	26.25	370 - 380	1/1
		1	26.5	360 - 380	3/1
	80	1	22.5	320 - 345	1/3
		1	23	350 - 355	2/0
		1	23.5	315 - 340	2/0
		1	24	300 - 350	4/1
	90	1	20	360 - 390	3/3
		1	21	343	1/0
Buckle 6	70	1	15	125 - 145	0/5
		1	16	135 - 150	0/5
		1	17	140 - 160	1/5
		1	17.5	150 - 160	3/2
		1	18	150 - 165	4/0
	80	1	14	155 - 180	1/4
		1	14.5	160 - 180	5/0
		1	15	185 - 220	5/0
	90	1	10	110 - 120	0/5
		1	11.5	150 - 175	0/5
		1	12	160 - 195	0/5
		1	12.5	190 - 220	0/5
		1	13	195 - 245	7/5
		1	15	265 - 300	5/0
Breed	70 - 90	1	15 - 30	175 - 380	No releases
Autoliv	70 - 90	1	15 - 30	140 - 390	No releases

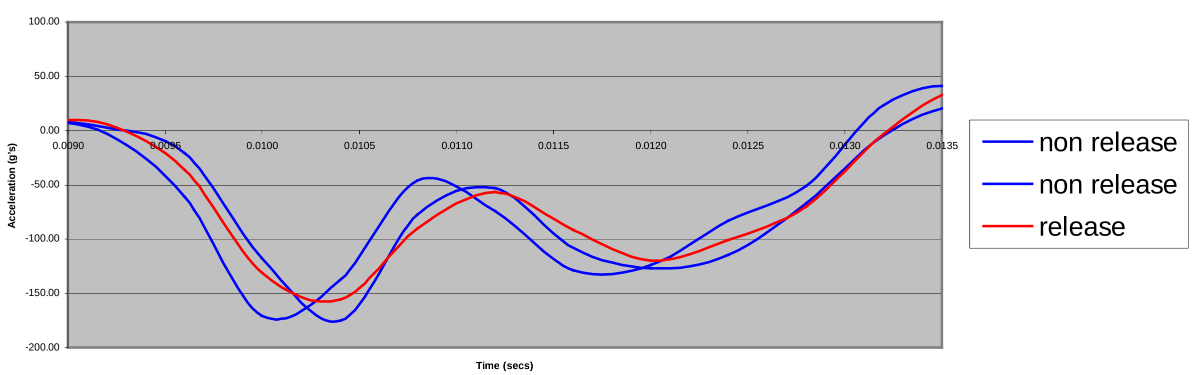

Figure 3. Graphical illustration of determining a change in velocity.

Table 3.
Associated Delta V's For Release and Non-Release for Buckle 6

Non Releases				
Duro	Test #	Delta v (g*secs)	Delta v (mph)	Peak Accel. (g's)
70	1	0.3295	7.23	145
70	2	0.3488	7.65	136
70	3	0.322	7.06	140
70	4	0.3653	8.01	136
70	5	0.3618	7.94	125
70	6	0.3566	7.82	140
70	7	0.3345	7.34	146
70	8	0.3545	7.78	149.5
70	9	0.3624	7.95	135
70	10	0.3653	8.01	137
70	11	0.3886	8.52	150
70	13	0.4018	8.81	156
70	14	0.375	8.23	148
70	15	0.3743	8.21	162
70	16	0.3714	8.15	143
70	19	0.3816	8.37	147
70	21	0.3947	8.66	159
80	6	0.3451	7.57	175
80	7	0.3476	7.63	170
80	9	0.3346	7.34	171
80	10	0.3386	7.43	177
90	11	0.1803	3.96	109
90	12	0.1863	4.09	123
90	13	0.1909	4.19	114
90	14	0.1957	4.29	122
90	15	0.1725	3.78	119
90	16	0.2486	5.45	148
90	17	0.2436	5.34	157
90	18	0.2518	5.52	173
90	19	0.2641	5.79	168
90	20	0.2512	5.51	155
90	21	0.266	5.84	177
90	22	0.2788	6.12	193
90	23	0.2811	6.17	187
90	24	0.2709	5.94	162
90	25	0.2695	5.91	185
90	26	0.2989	6.56	213
90	27	0.2944	6.46	217
90	29	0.2949	6.47	213
90	30	0.2852	6.26	193
90	31	0.3157	6.93	227
90	32	0.2967	6.51	209
90	35	0.3063	6.72	201
90	36	0.3157	6.93	210
90	37	0.3088	6.77	194

Releases				
Duro	Test #	Delta v (g*secs)	Delta v (mph)	Peak Accel. (g's)
70	17	0.3812	8.36	156
70	18	0.3928	8.62	152
70	20	0.3993	8.76	159
70	22	0.396	8.69	158
70	23	0.3864	8.48	165
70	24	0.4026	8.83	151
70	25	0.3923	8.61	150
80	1	0.3825	8.39	186
80	3	0.4379	9.61	218
80	4	0.3918	8.59	203
80	5	0.3882	8.52	197
80	8	0.3404	7.47	156
80	11	0.3671	8.05	179
80	12	0.3748	8.22	185
80	13	0.3517	7.72	162
80	14	0.356	7.81	175
80	15	0.3621	7.94	179
90	1	0.3836	8.41	271
90	2	0.4031	8.84	283
90	3	0.4024	8.83	263
90	4	0.3822	8.38	299
90	5	0.3936	8.63	301
90	6	0.3209	7.04	215
90	7	0.3232	7.09	237
90	8	0.2857	6.27	188
90	9	0.3346	7.34	243
90	10	0.3189	7.00	234
90	34	0.3171	6.96	214

As mentioned earlier, and as shown in the above table, there is a maximum value for consistent non-release, a minimum value for consistent release, and a range of values for which release will sometimes occur.

For Buckle 6 tested at a 2.5 kHz sampling rate, the maximum value for consistent non-release was shown to be 0.3 g*secs which corresponds to a delta v of 6.58 mph. A minimum value for consistent release was 0.43 g*secs (9.43 mph). The range from 0.3 to 0.43 is the area in which release or non-release could not be predicted based on the delta v value.

The change in velocity was determined with peak accelerations. I the exact time of release could be determined, a more accurate relationship could be developed.

Table 4.
Associated Delta V's For Release and Non-Release for Buckle 3

Duro	Test #	Delta v (g*secs)	Delta v (mph)	Peak Accel. (g's)
Non Releases				
70	3	0.4152	9.11	206
70	4	0.4435	9.73	223
70	5	0.4937	10.83	225
70	6	0.5101	11.19	256
70	7	0.5657	12.41	264
70	9	0.5587	12.26	284
70	10	0.4758	10.44	242
80	1	0.5992	13.14	270
80	2	0.5736	12.58	282
80	3	0.6185	13.57	281
80	5	0.6396	14.03	296
90	1	0.5587	12.26	297
Releases				
Duro	**Test #**	**Delta v (g*secs)**	**Delta v (mph)**	**Peak Accel. (g's)**
70	8	0.5746	12.60	260
70	11	0.6806	14.93	241
70	12	0.5575	12.23	310
80	4	0.6545	14.36	311
80	6	0.6418	14.08	322
80	7	0.6855	15.04	340
90	2	0.6276	13.77	325
90	3	0.6188	13.57	309

For Buckle 3 tested at 2.5 kHz, similar conclusions were drawn. The largest value for delta v for which only non-releases occurred was 0.56 g*secs or 12.28 mph. The lowest value above which only releases occurred was 0.64 g*secs (14 mph). Values between 0.56 and 0.64 constitute the area where some released and some did not.

Effects of Pre-Loading on Inertial Release

Buckle 2, the NSB1055, and Buckle 3 were tested to determine the effects of pre-loading on inertial release. Table 5 is a composite of tests with pre-loads ranging from as little as 2 lbs to as much as 100 lbs. Results indicated that as pre-load tension increased, the required acceleration to provoke inertial unlatching also increased. Tests showed that the Warner KK buckle would release until pre-load tension exceeded 100 lbs. Buckle 2 would release until pre-load tension exceeded 75 lbs. Buckle 3 showed no releases with 50 lbs or more of pre-load tension.

Table 5a.
Pre-loads Associated with Release and Non-Release

Buckles	Durometer	Pre-Load (lbs)	Cylinder Pressure (psi)	Release
Buckle 2	90	2	20	yes
		25	20	no
		25	22	no
		25	23	yes
		50	23	no
		25	24	yes
		50	24	yes
		25	25	yes
		50	25	yes
		75	25	no
		75	30	no
	80	2	25	yes
		50	25	no
		2	30	yes
		50	30	no
Buckle 3	90	2	20	yes
		50	20	no
		50	25	no
		50	30	no
	80	2	25	yes
		50	30	no
	70	2	30	yes
		50	30	no

Table 5b.
Pre-loads Associated with Release and Non-Release

Buckles	Durometer	Pre-Load (lbs)	Cylinder Pressure (psi)	Release
NSB1055	90	2	14	yes
		10	14	no
		20	14	no
		3	15	yes
		5	15	yes
		8	15	no
		10	15	no
		20	20	yes
		30	20	no
		30	20	yes
		30	20	yes
		40	20	no
		40	20	yes
		40	20	yes
		45	20	no
		50	20	no
		50	20	yes
		60	20	no
		70	20	yes
		100	20	yes
		125	20	no
		150	20	no
		200	20	no
	80	3	20	yes
		20	20	yes
		50	20	yes
		70	20	yes
		100	20	no
	70	2	25	yes
		20	25	yes
		50	25	no

Effects of Flexible Buckle Mounting

Buckle 2 was mounted with flexible webbing in the test cage. The buckle was then tested with the 90 durometer at the maximum pressure setting for the test apparatus. The maximum pressure setting produces the highest velocity for the sled. The buckle was then tested at various pre-loads ranging from 2 to 150 lbs as seen in table 6. The buckle did not release during any of the testing when mounted with the flexible webbing.

Table 6.
Effects of Buckle Mounted With Webbing

Buckle	Pre-Load (lbs)	Cylinder Pressure (psi)	Durometer	Release
Buckle 2	2	18	90	no
	2	30	90	no
	50	30	90	no
	100	30	90	no
	150	30	90	no
For these tests the buckle mounted with webbing				

CONCLUSIONS

From these tests it becomes very obvious that some seatbelt buckles will release when subjected to certain conditions. It may be concluded that acceleration alone is not responsible for the inertial unlatching of seatbelt buckles. However, there does appear to be correlation between the change in velocity and when a buckle will release. A rapid change in velocity is much more likely to produce conditions for inertial release. If the exact time of release can be determined, then it may be possible to more accurately relate the change in velocity to inertial release.

Inertial release may occur when a hard connection is utilized between the buckle and the floorboard or seat of the vehicle. This hard or rigid stalk becomes the medium which transmits the high amplitude accelerations directly to the buckle. Thus, the unlatching of the buckle is due to a pushing of the buckle by the stalk. Merely adding the damping effects of webbing or a rubber isolator may be sufficient to prevent the conditions for which inertial releases occur.